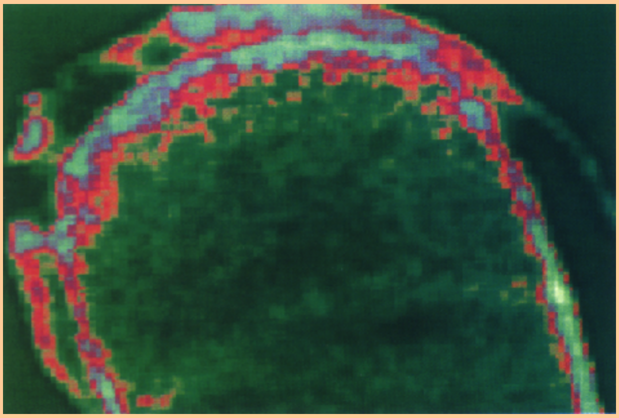
SYNCHROTRON

Light is one of the most important tools of science. It is the key to viewing the universe – from distant galaxies to cells, molecules, and even atoms. Visible light, which enables us to see the objects around us, is easy to generate and detect. The sun, electric lamps, and fire produce it; our eyes and photographic film detect it. However, visible light constitutes only a minor fraction of the electromagnetic spectrum. The remainder of the electromagnetic spectrum consists of radiation with longer or shorter wavelengths. On the longer wavelength side are radio waves, microwaves, and infrared radiation; on the shorter wavelength side are ultraviolet radiation, X-rays, and gamma rays. Because radiation throughout the electromagnetic spectrum is necessary to probe matter and fundamental processes, new and improved radiation sources are constantly being sought. During the past two decades, synchrotron radiation light sources have emerged as one of the most important and versatile tools for the production of radiation with wavelengths spanning the infrared to the X-ray regions.

Synchrotron radiation is the name given to light radiated by an electric charge following a curved trajectory-for example, a charged particle under the influence of a magnetic field. Synchrotron radiation is a natural phenomenon that has existed since the Big Bang. It is in the starlight that we see at night, generated by charged particles of matter spiraling through the cosmos. Nearly 100 years ago, theorists postulated the mechanism for the creation of synchrotron radiation. However, a manmade, controllable



source of such radiation was not found until the middle of the twentieth century when accelerators for charged particles first appeared. High-energy electron accelerators emerged as viable synchrotron radiation sources because, as electrons approach the speed of light, the synchrotron radiation increasingly is emitted in a narrow, forward-directed cone. Thus, the radiation is concentrated in a small solid angle and can be readily used by researchers.

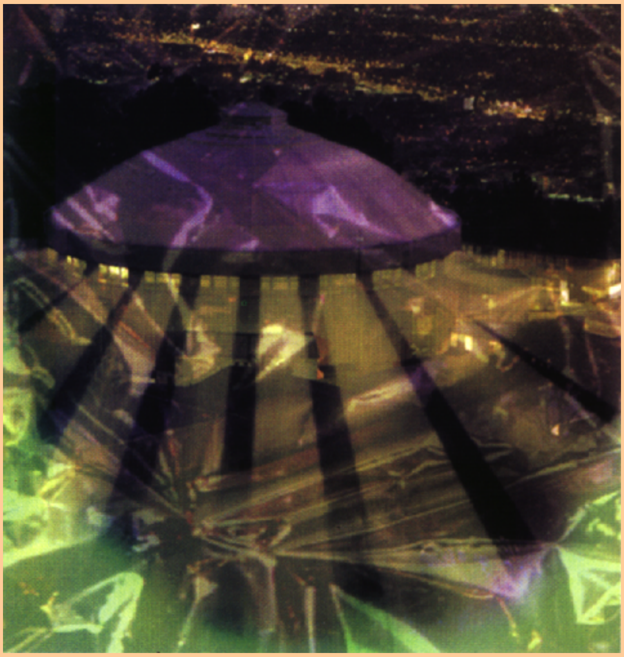
Early synchrotron light sources used photons that were created as the undesirable by-product of electron accelerators operated for high energy physics research. This parasitic use of synchrotron radiation showed such high promise that in the 1980's accelerators were built expressly for the purpose of generating synchrotron radiation. These accelerators, called "second-generation" synchrotron radiation light sources, typically consisted of a number of curved sections, in which the synchrotron radiation was generated, connected by straight sections; together, the curved and straight sections formed a closed, approximately circular orbit.

In the late 1970's, researchers developed devices consisting of periodic arrays designed to produce a series of deflections of the charged particle beam in the place of its straight-line orbit. Such devices are inserted into the straight sections of the storage ring (and hence are called "insertion devices") with one array of magnets above and one array below the charged particle beam path. As the charged particles pass through the alternating field, their deflections produce extremely intense synchrotron radiation: Insertion devices can be configured either as "wigglers" or "undulators" depending upon the effect they are to have on the movement of the charged particle beam. In general, wiggler magnets produce intense, energetic radiation over a wide range of energies, while undulator magnets produce radiation of selected energies (harmonics) at high brilliance. Most synchrotron light sources have several insertion devices, but those designed principally to use insertion devices are termed 'third generation' synchrotron light sources. The two third generation sources in the United States are the Advanced Light Source at Lawrence

LIGHT SOURCES

Berkeley National Laboratory, optimized to provide radiation in the ultraviolet/soft X-ray region of the spectrum, and the Advanced Photon Source at Argonne National Laboratory, optimized to provide radiation in the hard X-ray region of the spectrum. Both were constructed and are operated by the Office of Basic Energy Sciences.

Researchers use a wide variety of experimental techniques when applying synchrotron radiation to their own problems. Most experiments fall into one of four categories: scattering, spectroscopy, imaging, and time-resolved studies. These relate to the four primary ways in which we describe the physical world: momentum (scattering), energy (spectroscopy), position (imaging), and dynamics (time). Often, forefront experiments will use a combination of these basic approaches, such as time-resolved X-ray scattering or spectrally selected imaging. Today, synchrotron radiation is used for state-of-the-art studies in materials sciences, physical and chemical sciences, geosciences, environmental sciences, biosciences, medical sciences, and pharmaceutical sciences.



The descriptors of synchrotron radiation that determine its properties and range of applicability are ***flux, brightness or brilliance, pulse length, tunability polarization and coherence. Flux,*** and ***brightness or brilliance*** are measures of the intensity of the radiation based on a measure of the number of photons per second in a narrow energy bandwidth (usually 0.1%) per unit solid angle. Flux is a measure of the intensity integrated over all vertical opening angles (above and below the plane of the electron orbit) of the photon beam and is the appropriate measure for experiments that use the entire unfocused X-ray beam. ***Brightness*** is the number of photons emitted per second, per square millimeter of source size, per square milliradian of opening angle, within a given spectral bandwidth (usually 0.1%). ***Brightness*** is a measure of the concentration of the radiation and increases as the size and divergence of the electron beam decrease. Undulators produce the brightest beams of synchrotron radiation. ***Brightness*** is often referred to as ***brilliance. Pulse length*** is the length of time that a burst of X-rays illuminates an experiment. ***Tunability*** is a measure of the useful wavelength range of the synchrotron radiation. ***Polarization*** is a measure of the alignment of the electric field vector of the light. Normally plane polarized, special undulators can alter the polarization to produce variable ellipticity and helicity, which will enable a wide variety of polarization-dependent studies. ***Coherence*** is a measure of the alignment of the phases of the electric field vectors of the light – i.e., a measure of the degree to which the waves are in phase across a light beam at any instant (transverse or spatial coherence) and the degree to which they remain so as the light propagates (longitudinal or temporal coherence). The high spatial and temporal coherence of the light from the ALS and APS undulators facilitates both tight focusing for microscopy and advanced imaging technologies such as holography.

The Office of Basic Energy Sciences operates four synchrotron light sources. In addition to the two third-generation sources mentioned above, there are two second-generation sources – the Stanford Synchrotron Radiation Laboratory (SSRL) and the National Synchrotron Light Source (NSLS).